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A THREE-SALT NUTRIENT SOLUTION FOR PLANTS

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From a survey of the literature bearing on the growth of plants in nutrient solutions, it appears that the experimental work most nearly approaching logical completeness is that recently carried out by Tottingham.¹ This writer employed 84 different solutions, all of approximately the same total osmotic concentration but each solution differing from all the others in its proportions of the four nutrient salts, mono-potassium phosphate, potassium nitrate, calcium nitrate, and magnesium sulphate. Besides these salts each solution contained the usual trace of iron, as ferric phosphate. Tests of the 84 different proportions of the nutrient salts, with total osmotic concentration (2.50 atmospheres diffusion tension) about the optimum for young wheat plants, showed that the best solution for the growth of tops (during the first four weeks after germination) contained the four salts in the following volume-molecular concentrations: KNO_3 , .0049m.; KH_2PO_4 , .0130m.; $\text{Ca}(\text{NO}_3)_2$, .0144m.; MgSO_4 , .0145m. The solution giving the greatest dry weight of tops showed an improvement over Knop's solution, of the same osmotic concentration, of 11 percent on the basis of dry weight of tops grown in Knop's solution. The solution above described is Tottingham's best solution for tops, and may be regarded as the most reliable standard nutrient solution for wheat during its first four weeks of growth, so far worked out. The present writer has repeated the test of Tottingham's optimal series of solutions and of Knop's solution (all with osmotic concentration of 2.50 atmospheres) with wheat, and the results are in very satisfactory agreement with those obtained by Tottingham. For tops,

¹ Tottingham, W. E. A Quantitative Chemical and Physiological Study of Nutrient Solutions for Plant Cultures. *Physiol. Researches* 1: 133-345. 1914.

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the best growth (measured by dry weight) occurred with the same proportions of salts as those giving the best growth in the earlier work. While Tottingham reports an improvement of 11 percent over Knop's proportions, the corresponding improvement here shown was 12 percent. This agreement between the two results becomes still more pronounced when it is noted that the two experiments were carried out in different years and at different seasons.

Since the general problem of the salt requirements of plants largely remains to be studied, and since nutrient solutions will surely have to be employed in experiments bearing on this problem, it is quite essential that the standard solution used as a basis of comparison be as simple as possible and that it produce excellent growth of the plants. That distilled water is not suitable for use as such a standard is obvious from the fact: (1) that this medium removes salts from the plants, and (2) that the plants in pure water become visibly unhealthy after a few days and soon cease to grow at all. One phase of this matter has been dealt with by True and Bartlett² and by True.³ It therefore seems highly desirable to devise a simpler solution than the four-salt mixture used by Knop and Tottingham, if this can be accomplished. An attempt was made in this direction, and the present announcement aims to state the main results in a preliminary way. A more complete account of this work will appear later.

Combinations of three nutrient salts, which contain all the essential elements required for plant growth besides iron, and which do not precipitate when mixed in solution of the needed concentration, are comparatively few. The solution here employed contained monopotassium phosphate, calcium nitrate, and magnesium sulphate; potassium nitrate is thus omitted from the Knop formula. These three salts contain all the essential elements except iron, and they dissociate in solution to form all of the ions present in the Knop-Tottingham four-salt solution. They do not readily precipitate when mixed in solution, and permit total concentrations suitable for plant growth. Thus the three-salt solution appears to be chemically adapted for the purpose in view. Growth tests are needed to show its suitability for supporting plant growth.

² True, R. H., and Bartlett, H. H. Absorption and Excretion of Salts by Roots, as Influenced by Concentration and Composition of Culture Solutions. U. S. Dep. Agr. Bur. Pl. Ind. Bull. 231. 1912.

³ True, R. H. Harmful Action of Distilled Water. Amer. Journ. Bot. 1: 255-273. 1914.

A method similar to that used by Tottingham was here employed, to give a series of solutions differing in the proportions of the three salts, but all having approximately the same total osmotic concentration as measured by the lowering of the freezing point.⁴ A trace of ferric phosphate was added to each solution. Each series contained 36 different solutions, instead of the 84 necessitated by the four-salt solution used by Tottingham. The plants here used were wheat (*Triticum vulgare*) (from the same lot of seed as was used by Tottingham) and buckwheat (*Fagopyrum esculentum* Moench.), and the seedlings were germinated and mounted in a manner similar to that employed by the earlier writer. All the three-salt solutions used in this comparison, including that with Tottingham's best proportions for wheat tops and the one with the regular Knop proportions, had approximately the same total osmotic concentration, but this was much lower than the concentration employed by Tottingham. They had a diffusion tension of 1.75 atmospheres (as measured by the lowering of the freezing point), while Tottingham's corresponding series showed 2.50 atmospheres. Both these concentrations lie within the optimum range for wheat. Tottingham's best solution for tops and the regular Knop's solution were included in this series for purposes of comparison. The cultures lasted 24 days, with change of solution every three days, the containers holding 250 cc.

The solution giving the best growth of wheat tops contained the three salts in the following volume-molecular partial concentrations: KH_2PO_4 , .0180m.; $\text{Ca}(\text{NO}_3)_2$, .0052m.; MgSO_4 , .0150m. This showed an improvement over Knop's solution, of the same total osmotic concentration, of 27 percent, while Tottingham's best solution here showed a corresponding improvement of but 16 percent. In the solution yielding the greatest dry weight of buckwheat tops the volume-molecular partial concentrations of the three salts were: KH_2PO_4 , .0144m.; $\text{Ca}(\text{NO}_3)_2$, .0052m.; MgSO_4 , .0200m. The improvement produced by this medium, in dry weight of buckwheat tops, over Knop's solution of the same total osmotic concentration, was 61 percent. The increase shown by Tottingham's best solution was 21 percent. The data here given represent averages from two series, one conducted in August and the other in October. The two corresponding series agreed, both for wheat and for buckwheat, in the

⁴ Shive, J. W. The Freezing Points of Tottingham's Nutrient Solutions. Pl. World 17: 345-353. 1915.

proportions of the three salts giving the greatest dry weight of tops. These results are expressed in the tabulated form below, with those of Tottingham's tests added for comparison.

RELATIVE DRY WEIGHTS OF TOPS OF WHEAT AND BUCKWHEAT GROWN IN VARIOUS SOLUTIONS

| Experimenter and Plant | Four-salt Solution | | | | Three-salt Solution | |
|------------------------|--------------------|-------------|----------------------------------|-------------|--------------------------|--------------------|
| | Knop's | | Tottingham's Best for Wheat Tops | | Shive's Best (1.75 Atm.) | |
| | (2.50 Atm.) | (1.75 Atm.) | (2.50 Atm.) | (1.75 Atm.) | For Wheat Tops | For Buckwheat Tops |
| Tottingham (wheat) .. | 1.00 | — | 1.11 | — | — | — |
| Shive (wheat) | 1.00 | — | 1.12 | — | — | — |
| Shive (wheat) | — | 1.00 | — | 1.16 | 1.27 | — |
| Shive (buckwheat) ... | — | 1.00 | — | 1.21 | — | 1.61 |

From these results it is clear that the three-salt mixture, with proper proportions, is not only eminently suitable for plant growth but that it gives a markedly better growth of tops than does either Tottingham's or Knop's four-salt solution, at least with a total osmotic concentration of 1.75 atmospheres, which is a suitable concentration for general water-culture work.

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